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Forest Ecology and Management 155 (2002) 171–185

Forest Ecology and Management

www.elsevier.com/locate/foreco

Using biological criteria and indicators to address forest inventory data at the state level

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Abstract

The Santiago Declaration identified seven criteria and 67 indicators for assessing the conservation and sustainable management of temperate and boreal forests. Data collected by the Forest Inventory and Analysis (FIA) program of the US Department of Agriculture Forest Service can be used to directly address at least 11 biological indicators.

The FIA program has conducted periodic inventories of forestland for several decades. These inventories provide statistical estimates of forest area, timber volume, growth, removals, and mortality. Recent legislation has mandated that the Forest Service inventory the forestland of the US on an annual basis measuring the entire set of national sample plots over a 5-year period.

This paper identifies which criteria and indicators can be addressed by FIA data; the scale at which it may be appropriate to use these data; and how recent changes will impact the Forest Service's ability to provide information needed to address these indicators. Data from the two most recent inventories of Iowa (1974 and 1990) and Minnesota (1977 and 1990) are used to show how criteria and indicators relate to trends in forest composition and extent, timber resource utilization, and the population size of native and non-native trees. These two states have distinctly different forest resources, ranging from sparse to dense, and provide a good test of the effectiveness of using forest inventory data to provide criteria and indicator information at the state level.

Analysis of the data for the last two inventories of Iowa and Minnesota reveals that the area of timberland has increased by 34 and 8%, respectively, while growing-stock volumes have increased by 47 and 23%. Volumes of most native species increased over the period, especially for pioneer species such as *Juniperus virginiana* L. [Little (1979). Agricultural Handbook No. 541, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO] (eastern red cedar). A notable exception was the 52% decline of *Ulmus americana* L. (American elm) due to the spread of Dutch elm disease. The number of non-native species also increased. In Iowa, the estimated number of live *Ulmus pumila* L. (Siberian elm) trees, a non-native species, went from 0 in 1974 to 675×10^3 in 1990. During the 1990 inventory of Minnesota another non-native species, *Ailanthus altissima* (Mill.) Swingle (tree of heaven), was sampled for the first time.

Keywords: Criteria and indicators; Forest inventory

1. Introduction

Sustainable forest management can be described as the practice of meeting the forest resource needs and values of the present without compromising the similar capability of future generations (Helms, 1998). A first step towards sustainable forest management is assessment and monitoring.

The international effort to develop guidelines for assessing forest sustainability has been under way for many years. A major step forward occurred in 1992

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0378-1127/02/$ – see front matter
PII: S0378-1127(01)00557-6

when the United Nations Conference on Environment and Development (Earth Summit) was convened in Rio de Janeiro. This conference addressed the environmental, economic, and social challenges facing the international community. The Earth Summit led to the International Seminar of Experts on Sustainable Development of Boreal and Temperate Forests held in Montreal in 1993. As a result of this initiative, the Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests was formed in 1994. This group is known as the ''Montreal Process'' Working Group.

In 1995, the Working Group developed seven criteria and 67 indicators at their sixth meeting in Santiago, Chile (Anon., 1995). Twelve countries have endorsed the ''Santiago Declaration'' between 1995 and 1999 and are currently involved in the Montreal Process: Argentina, Australia, Canada, Chile, China, Japan, Republic of Korea, Mexico, New Zealand, the Russian Federation, the US, and Uruguay.

Criteria and indicators were established for country level reporting and were not intended for use at the forest management unit level. They were selected to aid in the development of policies that would support sustainable forest management at the national level and provide a common framework for monitoring and assessing trends. The first five criteria, containing a total of 28 indicators, deal with biological aspects of forests. They are (1) conservation of biological diversity; (2) maintenance of productive capacity of forest ecosystems; (3) maintenance of forest ecosystem health and vitality; (4) conservation and maintenance of soil and water resources; (5) maintenance of forest contributions to global carbon cycles. The sixth criterion addresses socioeconomic aspects, and the seventh criterion relates to the legal and institutional framework, and its impact on the conservation and sustainable management of forests.

In the US, programs have been in place to measure the sustainability of the nation's forests for nearly 70 years. As the meaning of forest sustainability has evolved, so have the monitoring programs. In 1928 Congress passed the McSweeny–McNary Act leading to the creation of the Forest Inventory and Analysis (FIA) program of the USDA Forest Service. At that time, sustainability focused on timber supplies. In 1974, with the passage of the Forest and Rangeland Renewable Resources Planning Act, the focus was broadened to look at integrated resource management. In 1990, the Forest Health Monitoring program was established to monitor and report on the nation's forest health. In 1998, the Agricultural Research, Extension, and Education Reform Act was passed which mandated annual inventories of all the nation's forestlands.

The primary objective of the FIA program is to inventory the US forestland to determine its extent and condition, and to provide estimates of timber volume, growth, removals, and mortality (Leatherberry et al., 1995). All of these estimates get to the heart of sustainability assessment as reflected in the number of indicators that FIA datasets are able to address.

The FIA unit of the Forest Service's North Central Research Station is one of five units responsible for inventorying the forests of the US. Data from these five units are combined to produce statistics on the nation's forests. These data will be used to address criteria and indicators at the national level, which in turn will be used to develop policies that will support sustainable management.

North Central's area of responsibility includes 11 midwestern states. Two of these states, Iowa and Minnesota, are neighbors with very different forest resources. Iowa has two broad ecoregions: the prairie ecoregion, characterized by alternating prairie and deciduous forest, extending over all but the northeastern corner of the state; and oak–hickory forests in Iowa's northeastern corner. Minnesota has three broad ecoregions: boreal forests in the north; hardwoods in the central and southeastern region; and cropland, once open prairie, in the west. Only 5.7% of Iowa's land area is forested compared to 32.8% for Minnesota.

These two states are the subjects of a case study for assessing the suitability of using forest inventory data to address some of the Santiago Declaration's criteria and indicators at the state level. While criteria and indicators were developed for use at the national and multi-national level, they are also of interest at a smaller scale such as at the state, ecoregion, or county level. In fact, in a letter to the Chief of the Forest Service (18 June 1997), the National Association of State Foresters expressed a desire to use criteria and indicators at the state level in resource assessments. This is reasonable given that states like Minnesota and Iowa are each roughly the size of Uruguay.

Because the goal of sustainability is to maintain a viable resource over time, inventory data are provided for two points in time. The most recent inventories for Iowa were conducted in 1974 and 1990. The most recent inventories for Minnesota were completed in 1977 and 1990. FIA data collected prior to 1974 for these two states is not available in computer accessible format. Information on these earlier inventories is limited to what is available in publications. Where practicable, data from earlier inventories are included to provide additional information on trends.

The objectives of this case study are to identify the extent to which the FIA program can provide criteria and indicator information for the assessment of forest sustainability at the state level and how recent changes in the FIA procedures will impact the ability of FIA to provide this information.

2. Methods

2.1. Sampling design

Area estimates were made using two-phase estimation methods (Loetsch and Haller, 1964). A preliminary estimate of area by land use is made from aerial photographs (Phase 1) and corrected by a subsample of field plot measurements (Phase 2). Each aerial photo plot represents approximately 77 ha. States have the option of increasing the intensity of ground plots measured by paying for the cost of intensification. Intensification provides improved accuracy at a smaller spatial scale. Minnesota chose to triple the intensity of ground plots in the heavily forested northern portion of the state. Iowa did not choose to intensify the number of ground plots.

In the 1990 inventory of Iowa, 201 969 photo plots were classified by land-use, and if forested further classified as to forest type and stand-size. A subsample of 12 769 photo plots was sent to the field for ‘‘ground truthing’’ or field measurements. On an average, a field plot in Iowa represents 1142 ha.

In Minnesota, 284 420 photo plots were classified. A sub-sample of 43 959 photo plots was sent to the field for ground truthing. On an average, a field plot in Minnesota, at the specified triple intensity, represents approximately 587 ha.

Field plots were established on timberland only. Timberland is defined as forestland that is capable of producing 1.4 m^3/ha per year of industrial wood crops under natural conditions, that is not withdrawn from timber utilization and not associated with urban or rural development. The area with trees must also be at least 36 m wide and 0.4 ha in size. In 1990, timberland accounted for 95% of forestland in Iowa and 88% of forestland in Minnesota.

Land incapable of producing 1.4 m^3/ha per year is classified as unproductive forestland while land withdrawn from timber utilization through statute, administrative regulation, or designation is referred to as reserved forestland. Field plots were not established on reserved and unproductive forestland prior to 1995. Because there were no field plots, there were no individual tree measurements to determine timber volume, growth, removals, and mortality. Area estimates and forest typing for reserved and unproductive forestland was based solely on Phase 1 aerial photo interpretation. In 1990 reserved and unproductive forestland accounted for 5% of the forestland in Iowa and 12% of the forestland in Minnesota.

Each timberland ground plot consisted of a 10-point cluster of variable radius sample points distributed evenly over approximately 0.4 ha. At each point trees 12.7 cm or more in diameter at breast height (dbh) were sampled using an 8.6 m^2/ha basal area factor variable-radius plot. Trees between 2.5 and 12.7 cm dbh were measured on a 13.5 m^2 fixed radius plot on all 10 of the points during the 1990 inventories but on only three points during the 1970’s inventories.

Prior to 1998 FIA units had modified their plot designs to more efficiently inventory the forests based on local conditions. As the need to compare data across state borders increased it became apparent that a common plot design was needed. Thus, in future inventories, under the annual inventory system, all five FIA units and the Forest Health Monitoring program will use the same fixed-radius plot design. This design consists of four 168.3 m^2 subplots for trees with dbh over 12.7 cm and four 13.5 m^2 subplots for seedlings and saplings.

2.2. Sampling error

The forest inventory sampling procedure is designed to provide reliable statistics at the state and multi-county levels. Because the inventory is a sample, the reported figures are estimates. A measure of reliability of these figures is given by sampling errors. The sampling error for the total area of timberland in Iowa in 1990 (787×10^3 ha) was 1.92%. This sampling error means that the chances are two out of three that if a 100% inventory had been taken, using the same methods, the resulting timberland area estimate would have been between 772×10^3 and 802×10^3 ha.

The sampling error for the 1990 Minnesota timberland area estimate was much smaller (0.36%) than the sampling error for Iowa primarily due to higher sampling intensity. A triple intensity survey was conducted throughout the heavily forested section of Minnesota, whereas only a single intensity survey was conducted in Iowa. A single intensity sample is adequate for observing the changes in area by forest type at the state level for Iowa (Table 1). In addition, a triple intensity inventory has proven to be satisfactory for observing the changes in area by forest type for some of the larger counties in Minnesota.

2.3. Forest type and stand-age classifications

The predominant tree species and its associates determine forest type (Eyre, 1980). The North Central FIA unit uses a plurality of stocking rather than basal area as the basis for forest typing. This approach allows plots in the seedling-sapling stand-size class having little or no basal area to be classified with a forest type.

Stand-age for the predominant stand-size class was estimated by boring (at dbh) three or more trees on or near the plot.

2.4. Volume and biomass estimates

The North Central FIA unit provides statistical estimates of the aboveground volume (including bark but excluding foliage) of all live trees over 2.54 cm dbh. Estimates of the biomass in herbs, shrubs, and tree seedlings (Smith and Brand, 1983) are also available but are based on a non-random subset of plots. Herb, shrub, and seedling data are collected only on plots measured between May and September and then only on the first three subplots. The total area inventoried on these three subplots is 10.1 m^2.

Regression equations were used to make individual tree volume estimates. Central States volume equations were used for Iowa (Hahn and Hansen, 1991) and Lake States volume equations were used for Minnesota (Hahn, 1984). The Central States volume equations use dbh and site index to compute volumes and biomass. The Lake States volume equations use dbh, site index, and basal area.

2.5. Removals estimates

The FIA program has two methods of computing removals. Estimates of current annual removals are provided by timber product output (TPO) studies.

Table 1
Area of timberland by major forest type and corresponding sampling error estimates in Iowa (1974 and 1990), and Minnesota (1977 and 1990) (in 10^3 ha)

State	Forest type	Area (1974)	S.E. (%)	Area (1990)	S.E. (%)	Change (%)
Iowa	Conifer	14	14.5	22	11.7	57
	Oak–hickory	294	3.2	362	2.9	23
	Elm–ash–cottonwood	166	4.2	203	3.8	22
	Maple	114	5.1	200	3.9	75
	Total	587	2.2	787	1.9	34
State	Forest type	Area (1977)	S.E. (%)	Area (1990)	S.E. (%)	Change (%)
Minnesota	Pine	309	1.6	363	1.5	18
	Spruce–fir	357	1.5	342	1.5	−4
	Lowland conifers	839	1.0	1097	0.8	31
	Aspen	2309	0.6	2221	0.6	−4
	Other hardwoods	1695	0.7	1935	0.6	14
	Total	5509	0.4	5958	0.4	8

Estimates of average annual removals are a product of forest inventory studies.

In TPO studies, all primary wood-using mills in a state are canvassed to determine the volume of roundwood harvested and processed in a given year (May, 1998). The most recent TPO studies for Iowa were conducted in 1988 and 1994. The most recent studies for Minnesota were conducted in 1990 and 1992. Although these studies provide good estimates of the volume of wood used by the timber products industry, they provide little insight into the amount of removals due to land-use change.

Forest inventory studies use remeasurement plots to calculate average annual removals from timberland. Average annual removals for a plot are calculated by dividing the total volume of removals due to harvest and/or land-use change by the length of the remeasurement period in years. The period between the most recent remeasurements was 16 years for Iowa and 13 years for Minnesota.

2.6. Identification of criteria and indicators to be addressed

The Santiago Declaration specifies seven criteria and 67 indicators. The first five criteria have 28 indicators, which address the biological aspects of the forest resource. The sixth criterion has 19 indicators, which address economic and sociological aspects of the forest resource. The seventh criterion has 20 indicators, which address the legal and institutional framework affecting the management of the nation's forest resources. FIA data can currently provide data for 11 of the biological indicators. FIA data can also be used in conjunction with other data sources to provide information on additional criteria and indicators, but these collaborative uses of FIA data are beyond the scope of this paper. Table 2 describes the 28 biological indicators and the ability of FIA to address them.

Most criteria and indicators require information for all forestland. In most cases, forest inventory data collected prior to 1995 can provide information only for timberland. Beginning in 1995, in an effort to match the requirements of criteria and indicators, the FIA program began collecting individual tree measurements on all forestland, not just timberland. Future inventories of Iowa and Minnesota will meet the requirement of reporting on all forestland.

3. Results

For clarity, examples rather than complete results are provided to illustrate that criteria and indicators can be used to address FIA data.

3.1. Extent of area by forest type relative to total forest area and timberland area (indicators 1 and 10)

Timberland in Iowa was estimated at 787×10^3 ha in 1990, up from 589×10^3 ha in 1974 (Table 1). Most of the new timberland came from land classified as pasture in 1974 but no longer grazed in 1990 (Brand and Walkowiak, 1991). These old fields are now occupied by stands dominated by *Ulmus americana* L. (22%), *Crataegus* sp. L. (7%), *Ulmus rubra* Muhl. (7%), and *Juniperous virginiana* L. (7%).

Between 1977 and 1990, the area of timberland in Minnesota increased from 5.5×10^6 to nearly 6.0×10^6 ha (Miles et al., 1995). Much of this increase came from land classified as unproductive in 1977 and reclassified as productive timberland in 1990 (Leatherberry et al., 1995). This typically occurred in the lowland conifer forest types, where the dominant species are *Picea mariana* (Mill.) B.S.P., *Thuja occidentalis* L., and *Larix laricina* (Du Roi) K. Koch.

The area of every forest type increased in Iowa between 1974 and 1990 (Fig. 1). The area in three of the five major forest types increased in Minnesota between 1977 and 1990, while the area in the aspen type declined and the area in spruce–fir remained nearly unchanged (Fig. 2). The decline in the area of the aspen type is due primarily to natural succession and increased harvesting pressures.

3.2. Extent of area by forest type and by age class or successional stage (indicator 2)

In both Iowa and Minnesota, the area in most forest type/stand-age classes increased between inventories. Two notable exceptions are the oak–hickory forest type in Iowa and the aspen type in Minnesota.

Oak–hickory is the most common forest type in Iowa. The area in oak–hickory stands in the 0–40-year age class decreased between 1974 and 1990 while the area in all other age classes increased (Fig. 3). This may indicate a problem with oak regeneration.

Table 2
The ability of FIA data to address the 28 biological indicators of the Santiago Declaration

Indicator	Indicator description	Can FIA data address this indicator?
1	Extent of area by forest type relative to total forest area	Yes
2	Extent of area by forest type and by age class or successional stage	Yes, for timberland areas. Stand-age information for unproductive and reserved forestland is available only for inventories conducted after 1995
3	Extent of area by forest type in protected area categories	Yes
4	Extent of areas by forest type in protected areas defined by age class or successional stage	No, for inventories conducted prior to 1995. Yes, for inventories conducted after 1995. Prior to 1995 individual tree measurements were not taken on reserved (protected) and unproductive plots
5	Fragmentation of forest types	No, however, FIA data are used to validate remotely sensed data that are used to analyze fragmentation
6	The number of forest dependent species	Yes. Limited to tree species
7	The status (rare, threatened, endangered, or extinct) of forest dependent species at risk of not maintaining viable breeding populations, as determined by legislation or scientific assessment	No. The sample size is insufficient to adequately address the status of rare tree species
8	Number of forest dependent species that occupy a small portion of their former range	No. The sample size is insufficient to adequately address the ranges of uncommon tree species
9	Population levels of representative species from diverse habitats monitored across their range	Yes. Limited to tree species
10	Area of forest land and net area of forest land available for timber production	Yes. FIA identifies forestland that is legislatively reserved from timber production
11	Total growing stock of both merchantable and non-merchantable tree species on forestland available for timber production	Yes
12	The area and growing stock of plantations of native and exotic species	Yes
13	Annual removal of wood products compared to the volume determined to be sustainable	Yes. FIA provides estimates of removals. FIA does not determine what is sustainable
14	Annual removal of non-timber forest products (e.g. fur bearers, berries, mushrooms, game), compared to the level determined to be sustainable	No
15	Area and percent of forest affected by processes or agents beyond the range of historic variation, e.g. by insects, disease, competition from exotic species, fire, storm, land clearance, permanent flooding, salinization, and domestic animals	No. The range of historic variation has not been determined. New FIA design will identify significant plot disturbances due to insects, disease, weather, fire, domestic animals, wild animals, and humans
16	Area and percent of forest land subjected to levels of specific air pollutants (e.g. sulfates, nitrate, ozone) or ultra violet B that may cause negative impacts on the forest ecosystem	No. FIA data could be used in conjunction with Forest Health Monitoring data and atmospheric data to develop estimates
17	Area and percent of forest land with diminished biological components indicative of changes in fundamental ecological processes (e.g. soil, nutrient cycling, seed dispersion, pollination) and/or ecological continuity (monitoring of functionally important species such as nematodes, arboreal epiphytes, beetles, fungi, wasps, etc.)	No
18	Area and percent of forest land with significant soil erosion	No
19	Area and percent of forest land managed primarily for protective functions, e.g. watersheds, flood protection, riparian zones	No

20	Percent of stream kilometers in forested catchments in which stream flow and timing has significantly deviated from the historic range of variation	No
21	Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties	No
22	Area and percent of forest land with significant compaction or change in soil physical properties resulting from human activities	No
23	Percent of water bodies in forest areas (e.g. stream kilometers, lake hectares) with significant variance of biological diversity from the historic range of variability	No
24	Percent of water bodies in forest areas (e.g. stream kilometers, lake hectares) with significant variation from the historic range of variability in pH, dissolved oxygen, levels of chemicals (electrical conductivity), sedimentation or temperature change	No
25	Area and percent of forest land experiencing an accumulation of persistent toxic substances	No
26	Total of forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class, and successional stages	Yes. Limited to aboveground biomass on timberland. Estimates for all forestland are available for inventories conducted after 1995
27	Contribution of forest ecosystems to the total global carbon budget, including absorption and release of carbon (standing biomass, coarse woody debris, peat and soil carbon)	No
28	Contribution of forest products to the global carbon budget	Yes. Timber product output studies provide estimates of biomass used for wood products

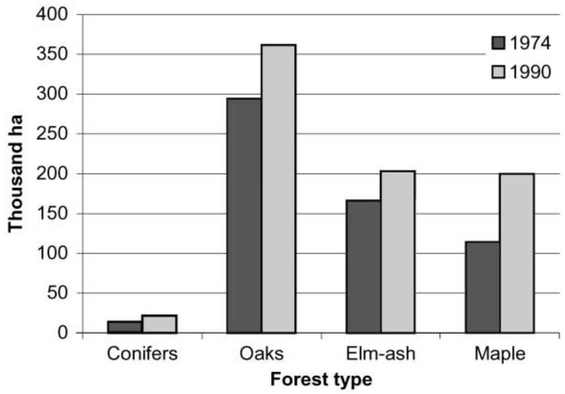

Fig. 1. Area of timberland by major forest type in Iowa (1974 and 1990).

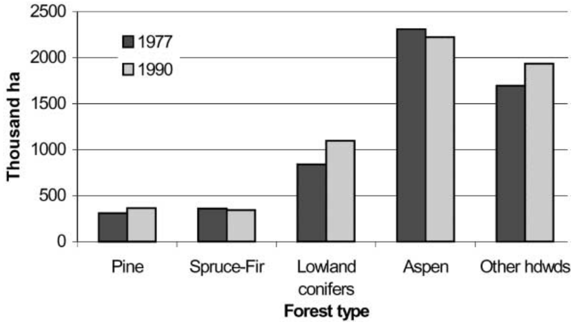

Fig. 2. Area of timberland by major forest type in Minnesota (1977 and 1990).

Aspen is the most common type in Minnesota. It is composed of pioneer species such as *Populus tremuloides* Michx. and *Populus grandidentata* Michx. The area in aspen stands in the 20–60-year age class

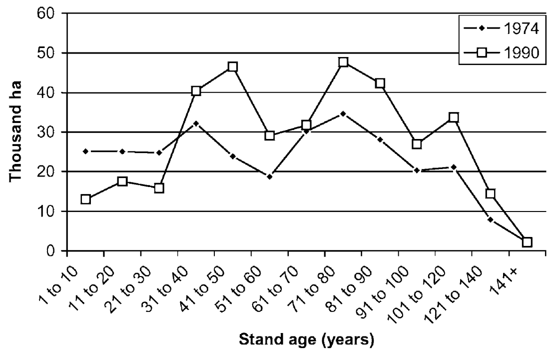

Fig. 3. Area of oak–hickory timberland by stand-age class in Iowa (1974 and 1990).

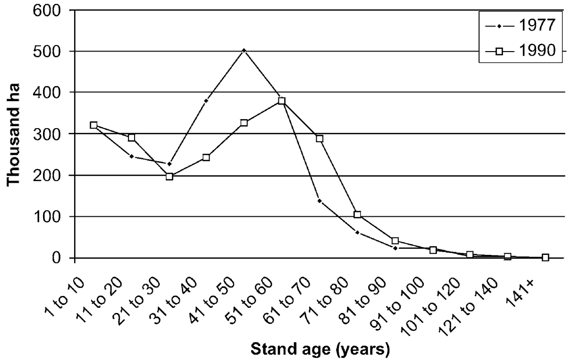

Fig. 4. Area of aspen timberland by stand-age class in Minnesota (1977 and 1990).

declined by 24% from 1.5×10^6 ha in 1977 to 1.1×10^6 ha in 1990 (Fig. 4). This decline is primarily due to natural succession and increased harvesting.

Also of interest is the 87% increase in the area of aspen over 60 years of age. Aspen stands rapidly deteriorate after age 60 (Harlow and Harrar, 1968). Analysis of FIA data shows that between 1977 and 1990 harvesting efforts were focused on older aspen stands. From a timber management perspective these efforts should be continued in order to capture the resource before it deteriorates.

3.3. Extent of area by forest type in protected area categories (indicator 3)

Iowa has an estimated 35.5×10^3 ha of reserved forestland. Over half of this area is in the oak–hickory forest type (54%) with the remainder in elm–ash–cottonwood (46%). Minnesota has an estimated 452.1×10^3 ha of reserved forestland spread over five forest types: pine 20%, spruce–fir 12%, lowland conifers 12%, aspen 40%, and other hardwoods 16%. State and national parks constitute the majority of these reserved forestlands. Because these plots were not visited on the ground, forest type classifications were made by photo interpreters rather than derived from individual tree measurements.

The area of protected forests in private ownership cannot be determined solely from FIA data. Privately protected forests range from those administered by organizations such as The Nature Conservancy to lands owned by individuals. In a 1994 national survey of private landowners, 34% of the landowners, whose ownership makes up 12% of the private forest acreage, said they intend to never harvest (Birch, 1996).

3.4. The number of forest dependent species (indicator 6)

Sixty-four tree species were identified in the 1990 inventory of Iowa—eight more than were identified in 1974. Fifty-four species were identified in both 1974 and 1990. Ten species not found in 1974 were sampled in the 1990 inventory. Three of the 10 (*Cercis canadensis* L., *Malus* sp. Mill., and *Prunus pensylvanica* L.f.) were noncommercial species and may have been present in 1974 but would have been classified as noncommercial species. Of the seven commercial species newly found (*Picea glauca* (Moench) Voss, *Acer rubrum* L., *Carya texana* Buckl., *Catalpa speciosa* Warder ex Engelm., *Morus alba* L., *Sassafras albidum* (Nutt.) Nees, and *Ulmus pumila*), only *U. pumila* (Siberian elm) was found on more than one plot. Two species, which had been observed in the 1974 Iowa inventory were not observed in the 1990 inventory (*Diospyros virginiana* L., and *Salix amygdaloides* Anderss.).

Siberian elm is an exotic often planted in windbreaks. Most Siberian elm trees identified in the 1990 Iowa inventory were found on plots that had reverted from pasture, wooded strips, or cropland to timberland. The estimate of the total number of live Siberian elm trees on timberland in Iowa rose from not encountered in 1974 to 675×10^3 in 1990. This represents a significant increase in a non-native species.

D. virginiana (common persimmon) is found throughout the southeastern US. Iowa is at the extreme northern and western extent of its range (Little, 1971). Persimmon was found on three plots in 1974. The largest tree was 2.5 cm dbh. The other trees were seedlings. No persimmons were found during the 1990 inventory. Given the low sampling intensity and scarcity of persimmon in Iowa it would be presumptive to conclude that there was a significant change in Iowa's persimmon population. Further study is needed to determine if this apparent decline is real or the result of an insufficient sample.

Sixty-four tree species were also identified in the 1990 inventory of Minnesota—eight more than were identified in 1977. Four of these species (*Acer pensylvanicum* L., *Ailanthus altissima*, *Morus rubra*, and *S. amygdaloides*) may have been present in 1977 but would have been classified as noncommercial species. The other new species (*Fraxinus profunda* (Bush) Bush, *Gleditsia triacanthos* L., *Populus alba* L., and *Ulmus alata* Michx.) were each found on only one plot.

A. altissima is native to central Asia and is considered a weed tree in the US. It is a prolific species, reproducing through seeding and vegetative sprouting. It also produces a toxin that inhibits the growth of other plants. This species should be monitored to determine the extent to which it is displacing native vegetation in Minnesota. Land managers may want to control *A. altissima* to minimize habitat degradation and possible loss of native species.

3.5. Population levels of representative species from diverse habitats monitored across their range (indicator 9)

Changes in the range and density of *U. americana* (American elm) between the 1977 and 1990 inventories are readily apparent in Figs. 5 and 6. (This type of geospatial information is available for every tree species found in Iowa and Minnesota.) The decline in American elm between inventories was mainly due to

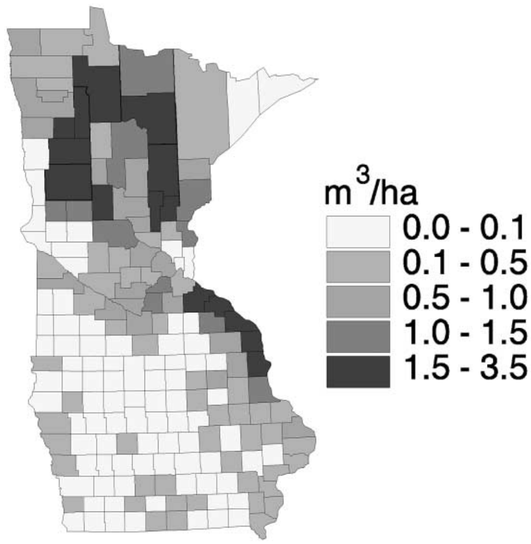

Fig. 5. Volume of *Ulmus americana* (m^3/ha) of land in Iowa (1974) and Minnesota (1977).

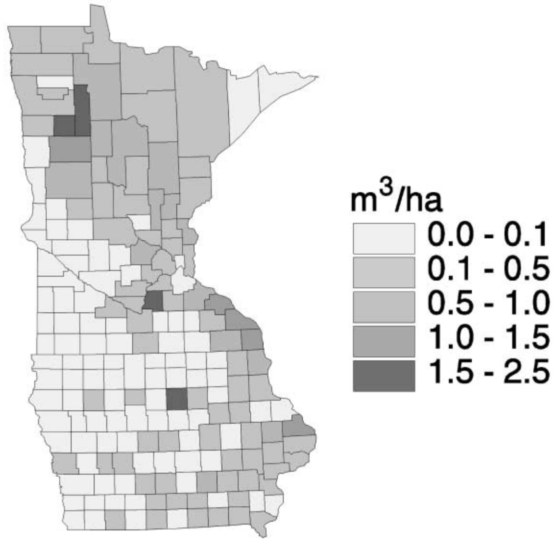

Fig. 6. Volume of *Ulmus americana* (m^3/ha) of land in Iowa (1990) and Minnesota (1990).

the spread of Dutch elm disease which is transmitted by bark beetles carrying the fungus *Ophiostoma ulmi* (Buism.) Nannf. (Brasier, 1991). Dutch elm disease was first reported in Iowa in 1957 and Minnesota in 1961 (Campana and Stipes, 1984). The impact on the elms increased with increasing exposure. The epidemic was in full swing during the 1970's inventories of Iowa and Minnesota. By the time of the 1990 inventories most of the damage had been done and the volume of American elm growing stock had declined by 52%.

3.6. Total growing stock of both merchantable and non-merchantable tree species on forestland available for timber production (indicator 11)

Forest inventory provides volume estimates with estimated sampling errors for every tree species. Table 3 lists the volumes by major species groups for Iowa and Minnesota. In Iowa, the net change in growing-stock volume increased between inventories for all species groups except black ash, sycamore, and butternut. In Minnesota, growing-stock volume increased for all species groups except elm and river birch.

The volume of *J. virginiana* (eastern red cedar) increased by 174% between inventories for Iowa and by 211% for Minnesota. The majority of this increase occurred on land that had reverted from pasture to forestland (Schmidt and Leatherberry, 1995).

3.7. The area and growing stock of plantations of native and exotic species (indicator 12)

Only two field plots representing 4168 ha of timberland in plantations were detected in the 1990 inventory of Iowa. One plot representing 2549 ha was planted to *Pinus strobus* L. and two non-native species (*Pinus resinosa* Ait., and *Picea glauca*). Neither plot had recordable growing-stock volume.

During the 1990 inventory of Minnesota, 277 field plots, representing 138×10^3 ha and 6.7×10^6 m^3, were determined to be timberland plantations. Only five plots, representing 2549 ha, were planted with non-native species (*Pinus sylvestris* L.). The sampling error estimates for area in plantations was 2.4% for Minnesota and 26.4% for Iowa.

3.8. Annual removal of wood products compared to the volume determined to be sustainable (indicator 13)

While not a measure of sustainable yield, average annual growth does provide some insight into whether the current level of removals can be maintained. Between inventories average annual growth exceeds average annual removals by 83% in Iowa (Fig. 7) and 76% in Minnesota (Fig. 8). Growth also exceeded removals for each major species groups. The major species groups include pine (*Pinus*), other softwoods (*Abies*, *Juniperus*, *Larix*, *Picea*, and *Thuja*), soft

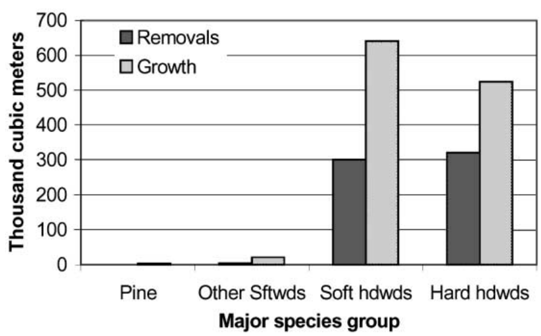

Fig. 7. Average annual growth and removals for Iowa (1974–1989).

Table 3
Growing-stock volume on timberland by species group with associated sampling errors in Iowa (1974 and 1990), and Minnesota (1977 and 1990) (in 10^3 m^3)

Species group	Iowa (1974)		Iowa (1990)		Change (%) (1974–1990)	Minnesota (1977)		Minnesota (1990)		Change (%) (1977–1990)
	Volume	S.E. (%)	Volume	S.E. (%)		Volume	S.E. (%)	Volume	S.E. (%)	
Jack pine	0	NA	0	NA	0.0	14025	5.2	15696	3.7	11.9
Red pine	0	NA	0	NA	0.0	11447	5.8	16578	3.6	44.8
White pine	0	NA	5	>100.0	NA	5924	8.0	7471	5.4	26.1
Ponderosa pine	0	NA	0	NA	0.0	5	>100.0	18	>100.0	282.4
White spruce	0	NA	0	NA	0.0	5764	8.1	8396	5.1	45.7
Black spruce	0	NA	0	NA	0.0	16858	4.7	21149	3.2	25.5
Balsam fir	3	>100.0	4	>100.0	24.4	25063	3.9	27305	2.8	8.9
Tamarack	0	NA	0	NA	0.0	8351	6.7	13479	4.0	61.4
Eastern red cedar	184	52.4	505	31.4	174.4	136	52.8	424	22.6	211.3
Northern white cedar	0	NA	0	NA	0.0	14035	5.2	21125	3.2	50.5
Other softwoods	0	NA	0	NA	0.0	37	>100.0	88	49.5	139.2
Select white oak	7514	8.2	9503	7.2	26.5	12805	5.4	18355	3.4	43.3
Other white oak	40	>100.0	48	>100.0	20.2	0	NA	0	NA	0.0
Select red oak	3905	11.4	5339	9.6	36.7	18657	4.5	23203	3.1	24.4
Other red oak	1439	18.7	2535	14.0	76.1	538	26.5	1044	14.4	94.1
Select hickory	1742	17.0	2977	12.9	71.0	321	34.3	463	21.6	44.1
Other hickory	512	31.4	965	22.7	88.4	142	51.7	278	27.9	96.5
Basswood	1804	16.7	3000	12.9	66.3	13969	5.2	19627	3.3	40.5
Yellow birch	0	NA	0	NA	0.0	462	28.6	619	18.7	34.0
Hard maple	1281	19.9	1341	19.2	4.7	8151	6.8	11437	4.3	40.3
Soft maple	3200	12.6	4626	10.4	44.5	4960	8.7	9781	4.7	97.2
Elm	2552	14.1	3531	11.9	38.3	15132	5.0	7657	5.3	−49.4
Black ash	43	>100.0	22	>100.0	−48.9	14067	5.2	19846	3.3	41.1
White and green ash	1014	22.3	1574	17.8	55.2	3180	10.9	5317	6.4	67.2
Sycamore	88	75.9	46	>100.0	−47.2	0	NA	0	NA	0.0
Cottonwood	2885	13.2	4291	10.8	48.7	771	22.2	1488	12.1	93.0
Willow	974	22.8	1094	21.3	12.4	636	24.4	832	16.1	30.8
Hackberry	487	32.2	1616	17.5	231.6	143	51.4	280	27.8	95.1
Balsam poplar	26	>100.0	64	88.3	141.6	16983	4.7	16884	3.6	−0.6
Bigtooth aspen	251	44.9	328	38.9	30.6	6113	7.9	7921	5.2	29.6
Quaking aspen	128	62.9	134	60.8	5.1	91841	2.0	108183	1.4	17.8
Paper birch	48	>100.0	68	85.7	40.1	38132	3.2	41330	2.3	8.4
River birch	344	38.3	478	32.2	38.9	3	>100.0	1	>100.0	−62.2
Black cherry	289	41.8	547	30.1	89.1	347	33.0	450	21.9	29.6
Black walnut	944	23.1	1805	16.6	91.3	225	41.0	401	23.2	78.0
Butternut	72	83.5	34	>100.0	−53.3	247	39.2	316	26.2	28.0
Other hardwoods	464	33.0	772	25.3	66.3	793	21.9	1469	12.1	85.4
Total	32236	4.0	47253	3.2	46.6	350262	1.0	428910	0.7	22.5

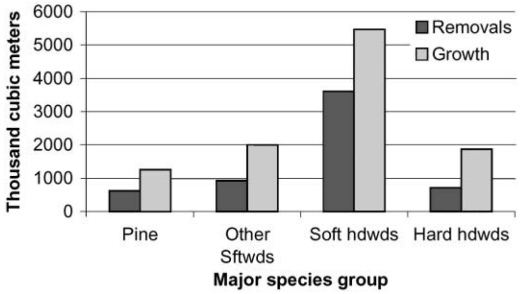

Fig. 8. Average annual growth and removals for Minnesota (1977–1989).

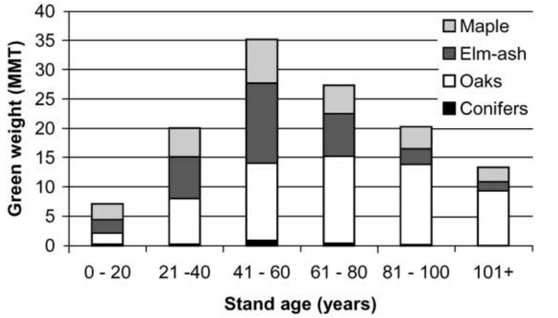

Fig. 9. Biomass of trees by forest type and stand-age in Iowa (1990).

hardwoods (hardwood species with a specific gravity of less than 0.5 such as *Populus* and *Tilia*), and hard hardwoods (hardwood species with a specific gravity of greater than 0.5 such as *Quercus* and *Carya*).

3.9. Total forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class, and successional stages (indicator 26)

Forest inventory calculates the aboveground biomass of all live trees over 2.54 cm on timberland plots. The total biomass calculated for Iowa in 1990 was 123 MMT (green weight). Twenty-eight percent was in the 41–60-year age class (Fig. 9). Forty-nine percent of the biomass was in the oak–hickory forest type, followed by the elm–ash–cottonwood type (28%), maple type (21%), and conifer type (2%).

The total aboveground biomass of all live trees on timberland in Minnesota in 1990 was 803 MMT (Fig. 10). Thirty-eight percent was in the other hardwoods forest type, followed by the aspen type (37%), lowland conifer type (13%), pine (6%), and spruce–fir (5%). Just as in Iowa, the greatest percentage of biomass (34%) was in the 41–60-year age class.

The Forest Service's Northern Global Change Research Program uses FIA data in their FORCARB model to generate estimates of a forests total carbon budget (Heath, in press).

Their 1992 estimate of the amount and disposition of carbon stored in the North Central region is 170 metric t/ha; 61% is stored in the soil, 29% in trees, 9% in the forest floor and 1% in the understory (Birdsey and Heath, 1995).

3.10. Contribution of forest products to the global carbon budget (indicator 28)

According to the 1994 TPO study for Iowa, 764×10^3 m^3 of woody material were removed from Iowa's forestlands in 1994 (Piva, 1997). Sixty percent

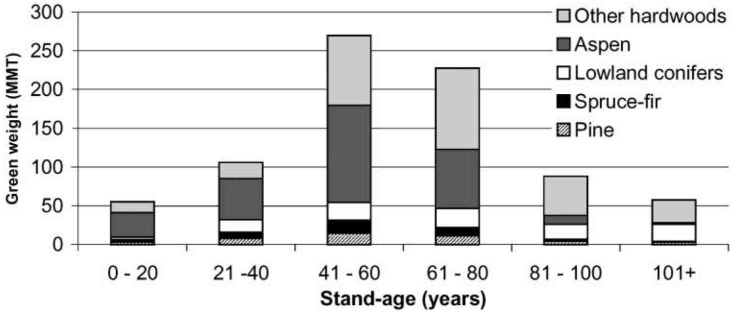

Fig. 10. Biomass of trees by forest type and stand-age in Minnesota (1990).

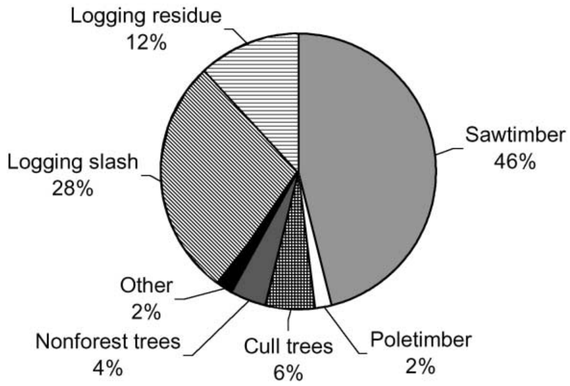

Fig. 11. Distribution of timber removals for industrial roundwood by source of material in Iowa (1994).

of this volume was used for wood products (Fig. 11). Twenty-eight percent was logging slash (unused portions of the non-merchantable sections of trees cut or killed by logging). The remaining 12% was logging residue (unused portions of the merchantable central stem of growing-stock trees cut or killed by logging).

The most recent TPO study of Minnesota estimated that 10.9×10^6 m^3 of woody material were cut in 1992 (Hackett and Dahlman, 1997). Sixty-nine percent of this material was used for wood products (Fig. 12). Twenty-seven percent was logging slash, and 4% was logging residue.

Of the volume used for wood products, approximately 35% of the total carbon removed is stored in

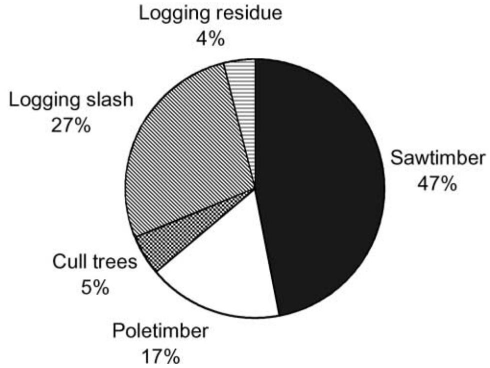

Fig. 12. Distribution of timber removals for industrial roundwood by source of material in Minnesota (1992).

products and landfills, 30% is returned to the atmosphere through decay or burning without energy production, and 35% is burned for energy (Heath et al., 1996).

4. Discussion

4.1. Shift of forest inventory emphasis from timberland to all forestland

In the past, FIA provided detailed information on timberland and only cursory information on reserved timberland and unproductive forestland (land not capable of producing 1.4 m^3/ha per year). In response to initiatives such as the Santiago Declaration, FIA has shifted its emphasis from timberland to forestland. As of 1999, individual tree measurements will be taken on all forestland plots to provide more complete information on criteria and indicators.

4.2. Shift from periodic to annual inventories

Trend data are obtained by comparing information from two or more inventories. The period between inventories was 16 years for Iowa and 13 years for Minnesota. Although this is a short time in the life of a tree, it is a long time in the life of a forest. Consider the forests of Iowa. In 1954, the timberland area of Iowa was 950×10^3 ha. By 1973, the area of timberland had dropped to 589×10^3 ha as land was converted to agricultural production. By the next inventory in 1990, the area in timberland had reversed course and climbed back to 787×10^3 ha.

In Iowa, more than 90% of timberland is privately owned. As a result, agricultural policy and commodity prices have a tremendous impact on the timberland base. Because of the long intervals between them inventories merely provide snapshots of the forest resource at certain points in time. Drastic changes to the forest resource can, and do, occur during an interval of 16 years. A shorter inventory cycle is needed to monitor the impacts of policy and economics on the forest resource.

Fortunately, the Forest Service has adopted an annual forest inventory system through which trends can be monitored yearly. Under the annual forest inventory system, 20% of a single intensity inventory will be conducted each year so that at the end of each 5-year period, an entire inventory is completed.

4.3. Changes in forest inventory plot design

Changes in plot design present challenges to monitoring some criteria and indicators. Although a change in plot design may not impact overall volume estimates, they do affect the probability of sampling additional tree species. A change in plot design is effectively a change in sampling intensity. For example, the area of fixed-radius subplots for measuring trees less than 12.7 cm dbh was only 40.5 m^2 during the 1970s but 135 m^2 in 1990. This change represented an increase in the sampling intensity of small trees and is likely to result in the inclusion of additional species. Other increasing or decreasing sampling intensities will have similar effects.

The last two inventories of Iowa (1974 and 1990) and Minnesota (1977 and 1990) were conducted using variable-radius plots. Fixed-radius plots will be used under the annual inventory system. This represents a change in sampling intensity and will cloud any comparison between species lists for past and future inventories. Once the annual inventory system is implemented, there should be no further changes in plot design.

4.4. Sustainability of the existing forest resource

In Iowa, forest economics and policy may have less of an impact on the resource than other agricultural economics and policy. In 1973, for example, when removals were 122% of growth in Iowa, 71% of the removals were due to land-use conversion as timberland was put into non-forest agricultural production. Only 29% of timber removals were due to harvesting. During the period from 1974 to 1989, non-forest agricultural lands reverted back into timberland, and average annual removals were only 55% of growth. It is not possible to determine a sustainable level of removals when the area in timberland is contracting and expanding to this extent.

Even when assuming the area in forestland will remain static, determining sustainability remains difficult. In Minnesota, for example, the rate at which aspen was harvested between 1977 and 1990 is not sustainable, but it moved the resource into a more sustainable condition by evening out the age class distribution.

The process of moving to a sustainable condition can take decades. Definitions of sustained yield often employ the concept of a fully regulated forest. A fully regulated forest using area control has an equal number of hectares in each age class and no age class is older than the desired rotation age. The desired rotation age for aspen is 60 years or less. The total acreage in the aspen type in 1977 was 2.3×10^6 ha. Under the concept of sustained yield from a regulated forest, there should be 383×10^3 ha in each 10-year age class.

Fig. 4 illustrates the unregulated condition of Minnesota's aspen resource in 1977. The acreage in each 10-year age class ranged from 228×10^3 ha in the 21–30-year age class to 504×10^3 ha in the 41–50-year age class. By 1990, Minnesota's aspen resource was in a more regulated condition. The acreage in each 10-year age class ranged from 198×10^3 ha in the 21–30-year age class to 379×10^3 ha in the 51–60-year age class. This move to a more regulated condition was due to a dramatic increase in the use of the aspen resource over the period. This use was responsible for the decrease in area of 20–60-year-old aspen stands and for the reduction of what would have been an even greater area of timberland occupied by over-mature aspen.

In Minnesota TPO studies show that harvest rates of aspen are continuing to increase. Do the snapshots of the forest in 1977 and 1990 show a resource moving into a more regulated condition or something else? As the supply of aspen dwindles and prices skyrocket, will the timber industry shift to less expensive species such as red maple and basswood? Criteria and indicators provide useful information to policymakers when they are derived from current information. It has been nearly 10 years since the last inventory of Minnesota. Annual inventories are needed to provide the public and policymakers with timely information. Then determinations can be made as to whether the current rate of harvesting is sustainable.

As the meaning of sustainability has evolved, so has the FIA program. The shift from a periodic inventory to an annual inventory will allow FIA to adapt quickly to changing needs. While the definition of sustainability is constantly evolving, its assessment will always depend, in part, on the tree data that FIA has historically collected.

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